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A new cue to figure–ground coding: top–bottom polarity

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Abstract

We present evidence for a new figure–ground cue: top–bottom polarity. In an explicit reporting task, participants were more likely to interpret stimuli with a wide base and a narrow top as a figure. A similar advantage for wide-based stimuli also occurred in a visual short-term memory task, where the stimuli had ambiguous figure–ground relations. Further support comes from a figural search task.

Figural search is a discrimination task in which participants are set to search for a symmetric target in a display with ambiguous figure–ground organization. We show that figural search was easier when stimuli with a top–bottom polarity were placed in an orientation where they had a wide base and a narrow top, relative to when this orientation was inverted. This polarity effect was present when participants were set to use color to parse figure from ground, and it was magnified when the participants did not have any foreknowledge of the color of the symmetric target.

Taken together the results suggest that top–bottom polarity influences figure–ground assignment, with wide base stimuli being preferred as a figure. In addition, the figural search task can serve as a useful procedure to examine figure–ground assignment.

Keywords: Perceptual organization; Figure–ground segregation

1. Introduction

In 1917, Rubin published his observations about the alternative perceptual organizations of his famous figure-vase stimulus. On the one hand, the stimulus can be interpreted as two faces looking at each other in front of a rectangle; on the other it can also be seen as a vase in front of the same rectangle, with the color of the rectangle now changed. In the many years that have since passed, research has indicated that figure–ground organization is influenced by a variety of cues including: Symmetry, convexity, surroundedness, area, familiarity and spatial frequency (see Palmer, 1999 for a discussion). Recently, Vecera, Vogel, and Woodman (2002) have added 'lower region' to this list. They demonstrated a bias in figure–ground organization such that the bottom half of a whole visual display tended to be taken as the figure, and the top half as the ground.

One of the problems in studying figure–ground organization is in choosing a task that reflects figure–ground coding, but that is not affected by other factors. In the vast majority of studies, observers have simply been asked to record what they saw as a figure (an explicit reporting task). However, this introspective process can be affected by many factors. For instance, with ambiguous stimuli there can be individual biases in maintaining or in wishing to switch from one organization to another, which can have quite dramatic effects on performance (e.g. Strüber & Stadler, 1999). An alternative procedure, less dependent on introspective biases, has been to use visual short-term memory tasks (VSTM-task, introduced by Driver & Baylis, 1996). For example, observers may be presented with an ambiguous figure–ground stimulus for a certain period

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(the study display), followed by a test display containing one of the regions from the ambiguous study display. The idea is that the figural region will have a stronger memory trace, so that the reaction times (RTs) will be faster when the subsequent region matches the perceived figure rather than the perceived ground in the study display (see Vecera et al., 2002, for an example). This method has become something of a gold standard in figure–ground research. Even this method, though, might not be without its problems. For instance, it is possible that effects in short-term memory tasks are caused by properties of the second, test display, rather than the original study display containing the ambiguous figure–ground stimulus.

So, it seems that, in order to establish that a certain cue influences figure–ground assignment, the prudent approach would be to use all the methods that are available, rather than to rely on a single approach. For instance, Vecera et al. (2002) used both explicit reporting tasks and the VSTM-method to establish that lower region is a figure–ground cue. In the present study we use both of the above procedures, plus also a new method (''figural search'') to establish another new cue for figure–ground assignment: top–bottom polarity. We use the evidence to argue both for the role of this new cue, and for the utility of figural search as a means to examine figure–ground coding.

We employed abstract shapes, depicted within a band pattern stimulus as used by Metzger (1936). Examples are shown in Fig. 1. The abstract shapes were constructed so that they had two long horizontal elements either at the base, and two short horizontal elements at the top (wide base) or two short horizontal elements at the base and the two long horizontal elements at the top (wide top). This resulted in a strong top–bottom polarity (see the Method).

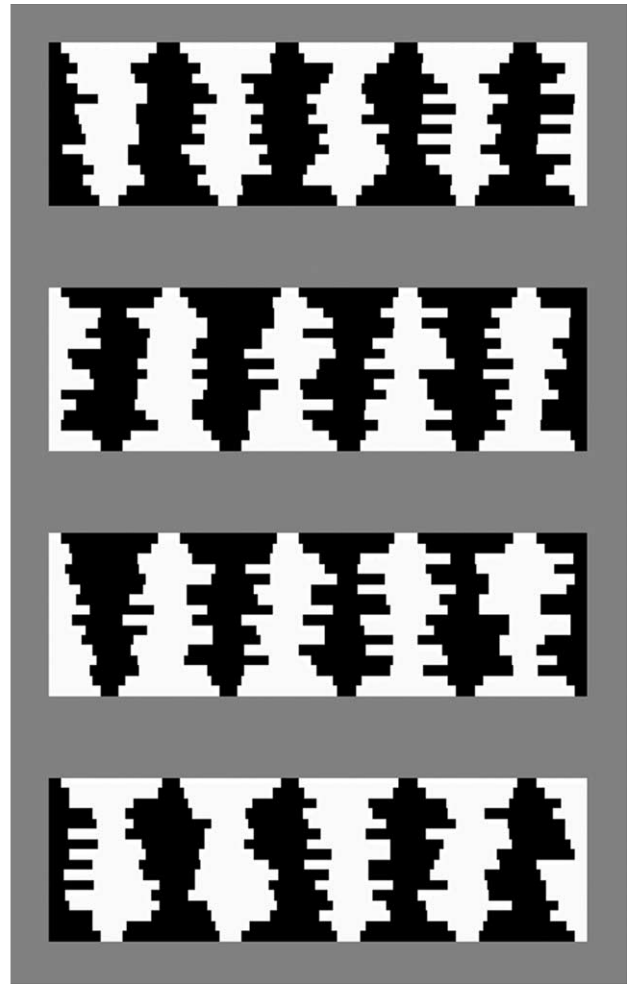


Fig. 1. The four stimuli used in Experiment 1.

2. Experiment 1: direct report

In Experiment 1 we used an explicit report task to provide direct evidence on any effect of top–bottom polarity on figure–ground coding. We presented a group of participants with ambiguous figure–ground displays. There were four displays (see Fig. 1), with the wide base regions being black for two displays and white for two displays (and vice versa for the wide top regions). For each display, participants had to decide whether the white or the black regions were seen as the figure.

2.1. Method

The study was run in a classroom testing situation. There were 55 participants (38 female, 17 male), all undergraduates in Psychology at the University of Birmingham (aged between 19 and 22). The four displays were shown one at a time, projected onto a large screen at the front of the classroom. The order of the displays was randomly determined. All the regions of the band patterns were asymmetric. Participants were not allowed to confer, and they made a written response to each display. In an initial pilot experiment, 22 observers were asked to view a pair of stimuli from the set used here, but with just a single element from the band patterns used to represent the 'wide top' and 'wide base' stimulus in each pair. A forced choice decision was then required as to whether the 'wide top' or the 'wide base' stimulus was upright. A set of 8 pairs was shown. Twenty participants chose all 8 stimuli with a 'wide base' as upright. One participant chose 1 stimulus as upright from the 'wide top' items. One other participant chose 3 stimuli with a wide top as upright. Thus overwhelmingly observers chose the 'wide base' items as upright.

2.2. Results

The percentages of the participants who reported the wide base shapes as figure were 89%, 76%, 84% and 71%

respectively, for the four displays. Tested binomially, all four percentages differ significantly from 50% (all p's < 0.001).

2.3. Discussion

There was a substantial and reliable bias in the explicit report of which part of an ambiguous display was perceived as 'figure'. Participants were biased to interpret the wide base regions as figural. This occurred irrespective of whether these regions were white or black. Note that all the regions were asymmetric, and that the participants were not engaged in a symmetry detection task. Therefore, the results cannot be attributed to effects of top–bottom polarity on symmetry perception, nor on symmetry biasing the figure–ground assignment.

As pointed out in the Introduction, explicit reporting methods need to be supplemented by more implicit methods, because the deliberate nature of explicit reporting tasks leaves open the possibility of extraneous factors. In the remainder of the experiments, we therefore used implicited methods, to provide converging evidence that top–bottom polarity acts as a figure–ground cue. In Experiment 2, we used the VSTM-task and in Experiments 3 and 4 we used a new implicit task, the figural search task.

3. Experiment 2: matching shapes in VSTM

In the VSTM task, participants are presented with a display with an ambiguous figure–ground relationship between black and white regions. This is followed by a pair of test shapes (unambiguous figures against the overall ground; see Fig. 2). The task is to decide which of the test shapes had a bounding contour that matched the border between the black and white regions. Performance is better if the contour of the matching test shape corresponds to the boundary of the figural region in the initial display (Driver & Baylis, 1996). Here we would expect a benefit when the contour matches the boundary of the wide base stimulus, rather than the wide top stimulus.

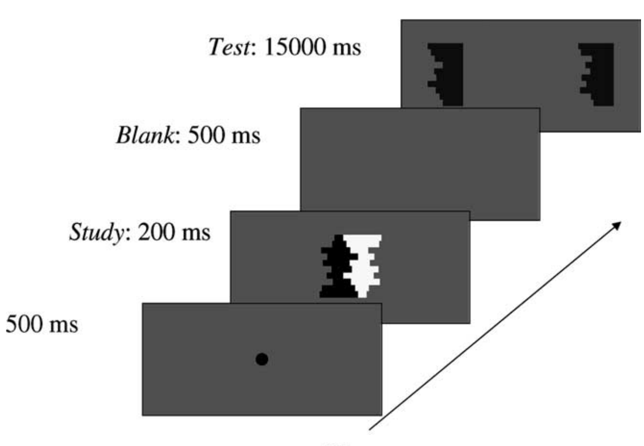


Fig. 2. Sequence of displays in Experiment 2. After the presentation of a fixation dot, the study stimulus was presented for 200 ms. After a 500 ms blank interval, the test display appeared. The test displays remained visible until response, or until 15 s had elapsed.

3.1. Method

3.1.1. Participants

Twenty-two participants (20 female, 2 male) were recruited either in return for course credit or for a small payment. All had corrected or corrected-to-normal vision, and they were unaware of the purpose of this experiment.

3.1.2. Apparatus

A Pentium III PC controlled the experiment and presented the stimuli on a 17 in. VGA-monitor, in 800×600 graphics mode.

3.1.3. Stimuli

The participants looked unrestrained at the stimuli from standard viewing distance (around 50 cm). The stimulus used in the study display contained two juxtaposed shapes, one black and one white ($3.7° \times 3.7°$), presented on a gray background. The test display contained two dark gray shapes ($2.1° \times 3.7°$). Examples are shown in Fig. 6. The study stimulus appeared at the center of the screen. The vertical size of an individual shape was 3.7°. A half of a shape consisted of 10 arms, each arm having a thickness of 0.37°. The maximum width of an arm was 1.1°. The minimum width was 0.2°. The shapes were always asymmetric. The shapes were rotationally symmetric. As a result, a shape and its 180° rotated version fit each other like a jig-saw when juxtaposed. This yields a natural control for non-specific effects on the figure–ground assignment, because the shape preferred as a figure and the shape preferred as a ground are identical. In this experiment we used 15 different shapes. Each shape was used 16 times: The wide-base shape could be on the left or on the right, the wide-base shape could be black or could be white, and the test display could contain a figural match for the wide-base shape or the wide-top shape, with the correct answer either on the left or the right.

3.1.4. Procedure

The participants were tested individually in a session that lasted approximately 20 min. After receiving the instruction for the task, participants performed a practice block of 16 trials. When they felt at ease with the task, they would start the experimental blocks, otherwise they would get another practice block of 16 trials.

A trial consisted of a fixation circle presented in the center of the screen for 500 ms. After the fixation circle disappeared, the stimulus was presented for 200 ms. After a blank display that lasted 500 ms, the test display appeared, and remained on the screen until the participant responded or 30,000 ms had passed. After the response, there was an inter-trial interval of 1000 ms, before a new trial would start (see Fig. 2). The task of the participants was to decide which of the two shapes presented in the test display had a bounding contour that corresponded to the border between the black and the white shape seen in the study display. If it was the shape on the left, they had to press the '\' on the keyboard as quickly as possible. For the shape on the right the '/' key was used.

3.1.5. Design

There were two within-subject factors: study position (wide base item left, wide base item right), and figural match (left item, right item). The factors were fully crossed (see Fig. 3 for examples of the four possible combinations). If top–bottom polarity biases figure–ground assignment, we would expect an interaction between these two factors: if during the study display the wide base item appears on the left, the figural match of the left item should be faster, but the figural match of the right item should be faster if the wide base item appears on the right during the study display. In total, there were 240 trials. The experiment was subdivided into blocks of 64. Between every block there was a self-paced break for the participant. If a participant made an error, the error trial was retaken somewhere in the sequence of trials. Each error resulted in an extra trial.

3.2. Results

The results are shown in Fig. 4. The data of one participant had to be discarded, because of an excessive error rate (proportion correct: 0.46). The data of the remaining 21 participants were entered into the analysis. Responses greater or less than 2.5 SDs from the cell mean (study position $\times$ figural match) for each partici-

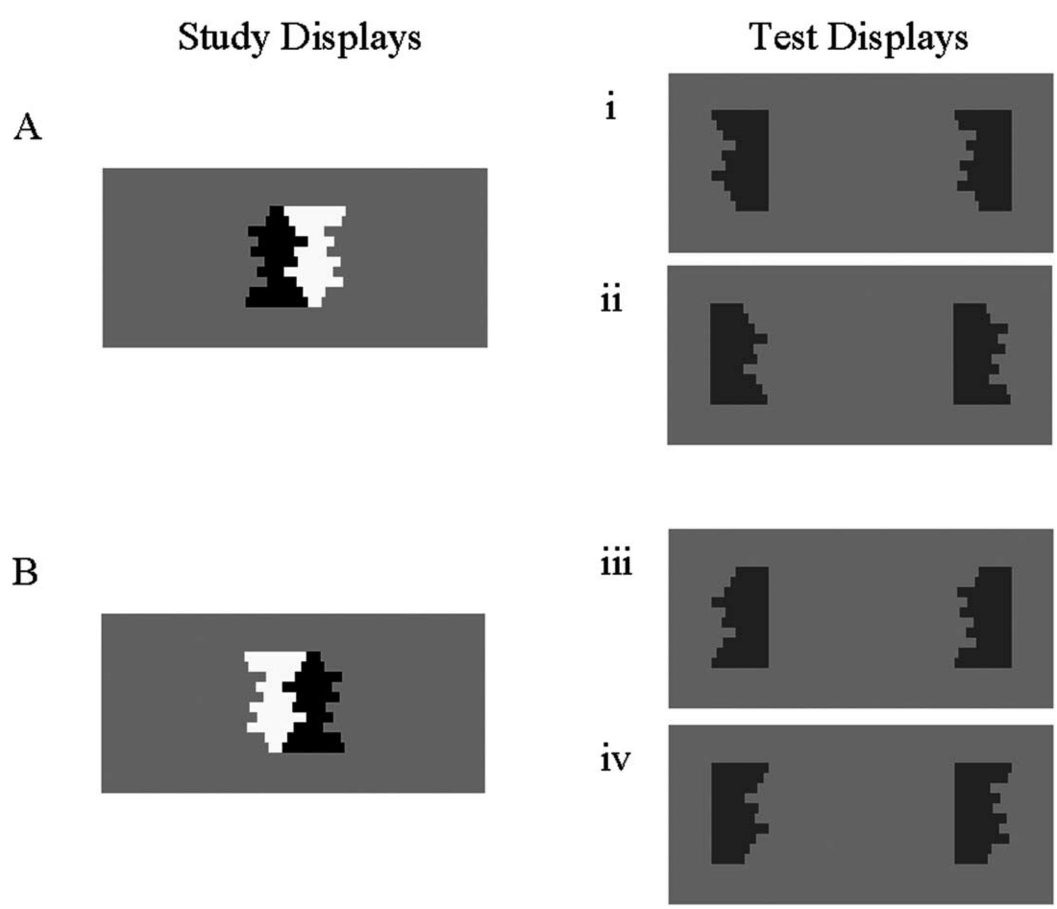


Fig. 3. Examples of the stimuli used in Experiment 2. (A) Stimulus with the wide base stimulus on the left and the wide top stimulus on the right: (i) test display with a figural match for the right item and (ii) test display with a figural match for the left item. (B) Stimulus with the wide base stimulus on the right and the wide top stimulus on the left: (iii) test display with a figural match for the right item and (iv) test display with a figural match for the left item.

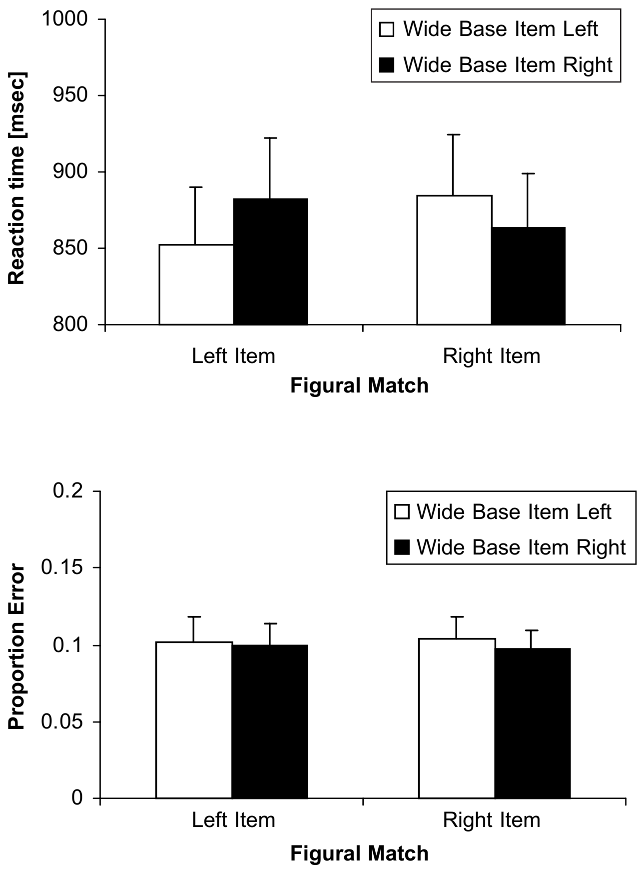


Fig. 4. Results of Experiment 2. Top panel: reaction times. Bottom panel: error proportions. White: wide base item on the left in the study display. Black: wide base item on the right in the study display. The error bars indicate standard errors.

pant were rejected. This resulted in rejection of 2.8% of the data. The error analysis was performed on all of the remaining trials, whereas the reaction time analysis only used the correct trials.

Critically, a two-way repeated measures ANOVA (study position × figural match) on the RT data yielded a significant interaction between study position and figural match, $F(1,20) = 5.042$, $p < 0.037$. Neither of the main effects was significant (both p's > 0.49).

A similar ANOVA on the error-data did not yield any significant effects. All p-values were 0.66 or above.

3.3. Discussion

The results of Experiment 2 support those obtained in Experiment 1. The interaction between study position and figural match indicates that there was an RT advantage for figural matches of the wide base region relative to matches contingent on the wide top region. This advantage is consistent with top–bottom polarity affecting figural assignment in the ambiguous displays.

Note that this result cannot be explained by effects of top–bottom polarity on symmetry detection, because all the shapes here were asymmetric. Also, all RTs are well within the range of times that have previously been accepted to be associated with figure–ground assignment (e.g. Driver & Baylis, 1996, Vecera et al., 2002).

In Experiments 3 and 4 we used a new implicit method: the figural search task. It combines elements of both the implicit (VSTM) and explicit report methods used in prior studies. The task provides an on-line measure (rather than a memory-based measure) of figure–ground assignment, [1] but one where (as with the memory tasks) observers are not explicitly required to report what they see as a figure. We presented observers with displays with ambiguous figure–ground relations, and asked them to find a particular target shape (in our case, a vertically symmetric item). We will call this task figural search, because it combines elements from figure–ground research with visual search. If a given cue leads to either an initial or dominant figure–ground organization, then the target shape revealed by this cue should be easier to find than a target shape not revealed by this cue. This then provides an indication that a particular cue influences figure–ground assignment. Our expectation, that it will take longer to detect a symmetrical shape when it belongs to the ground, is based on results reported by Baylis and Driver (2001). They showed that is more difficult to detect symmetry when the symmetrical edges belong to two different shapes (as is the case when the target shape is seen as belonging to the ground), than when the symmetrical edges belong to a single shape (as is the case when the target shape is seen as belonging to the figure).

4. Experiment 3: figural search for a known target color

In Experiment 3, participants were set to search for a symmetrical target amongst asymmetrical distractors. The target was also coded by color (either black or white, against a gray background). Under these circumstances, participants should parse figural from ground regions using color. The stimuli (abstract shapes) could either have a wide base, or a wide top. We ask whether the top–bottom polarity of the stimuli affected performance, even when figure–ground organization should be based on color. We note that, although the task was symmetry detection, there was only one symmetrical shape in a display. Hence, figure–ground should not be overwhelmingly determined by symmetry-effects of color and top–bottom polarity may thus still emerge (as indeed we observed).

[1] With on-line, we mean that the participants make their response while the ambiguous figure–ground stimulus is still available for inspection.

4.1. Method

4.1.1. Participants

Sixteen participants (13 female, 3 male) were recruited either in return for course credit or for a small payment. All had corrected or corrected-to-normal vision, and they were unaware of the purpose of this experiment.

4.1.2. Apparatus

A Pentium III PC controlled the experiment and presented the stimuli on a 17 in. VGA-monitor, in 800×600 graphics mode.

4.2. Stimuli

The participants looked unrestrained at the stimuli from a standard viewing distance (around 50 cm). The stimuli were black and white band patterns ($3.7° \times 12.4°$), presented on a gray background. Examples are shown in Fig. 5. The band patterns appeared at the center of the screen. Each band pattern contained eight complete objects and two half objects. Half of them were black, the other half were white. The vertical size of an individual shape was 3.7°. A half of a shape consisted of 16 arms, each arm having a thickness of 0.2°. The maximum width of an arm was 1.1°. The minimum width was 0.2°. The arms of a half were paired: the arm at the top end with the arm at the bottom end, the second arm from the top with the second arm from the bottom, etc. The lengths of a pair of arms had to sum up to 1.4°. For the wide base stimuli, the halves were constructed in such a way that the two arms at the bottom end of the shape always (nearly) had the maximum width. Consequently, the two arms at the top end always (nearly) had the minimum width. For the wide top stimuli, this was inverted. The lengths of the other arms were randomly chosen to be between the minimum width and the maximum width. Complete objects were created by combining two halves. In the case of an asymmetric object, the halves were constructed independently, for symmetric objects the same half was used twice.

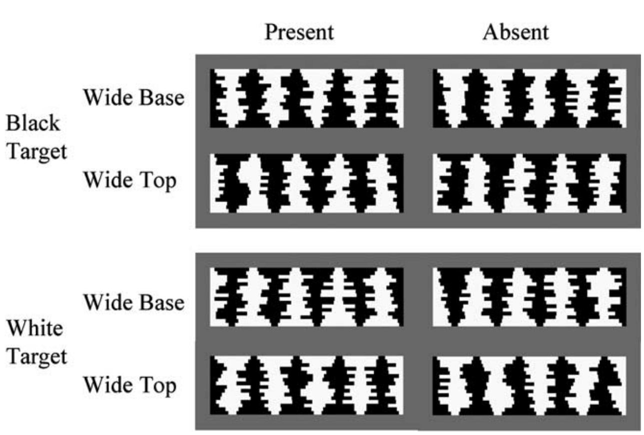


Fig. 5. Examples of displays with ambiguous figure–ground relations used in Experiments 3 and 4. Top half: target color black; and Bottom half: target color white.

An individual band pattern was used four times: Once with the wide base items colored black and the wide top items colored white, once with this color assignment inverted, and both these versions were also presented upside down.

4.2.1. Procedure

The participants were tested individually in a session that lasted approximately 40 min. After receiving the instruction for the task, participants performed a practice block of 16 trials. When they felt at ease with the task, they would start the experimental blocks, otherwise they were given another practice block of 16 trials.

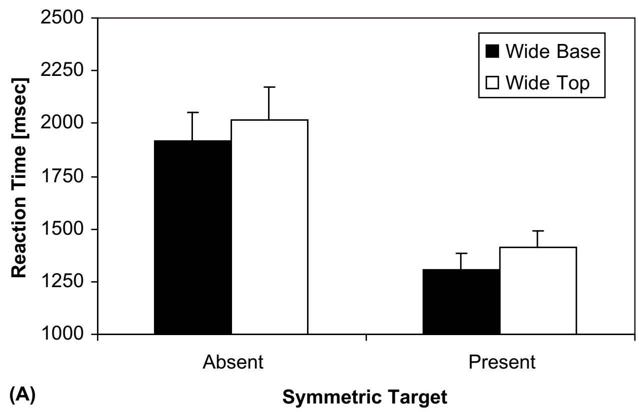
A trial consisted of a fixation cross presented in the center of the screen for 1000 ms. After the fixation cross disappeared, the band pattern was presented until the participant responded or 15,000 ms had passed. After the response, there was an inter-trial interval of 1000 ms, before a new trial would start. The task of the participants was to look for a vertically symmetric object of a specified color on the screen. If it was present, they had to push the 'Z' or 'M' key on the keyboard as quickly as possible. If it was absent, they had to push the other key ('M' or 'Z'). The keys assigned to present and absent responses were counterbalanced over participants.

4.2.2. Design

There were three within-subject factors: top–bottom polarity (wide base, wide top), target presence (symmetric target present, symmetric target absent), and the color of the stimuli (black, white). All the factors were fully crossed. In total, there were 640 trials. The target colors were blocked, resulting in two groups of 320 trials. The groups contained blocks of 80 trials. Between every block there was a self paced break for the participant. If a participant made an error, the error trial was retaken somewhere in the sequence of trials. Each error resulted in an extra trial. After the first target color was tested, there was a new training sequence of sixteen trials, to give the participants the opportunity to acquaint themselves with the new target color.

4.3. Results

The results are shown in Fig. 6. Responses greater or less than 2.0 SDs from the cell mean (top–bottom polarity $\times$ target presence $\times$ color) for each participant were rejected. This resulted in rejection of 4.2% of the data. The error analysis was performed on all of the remain-



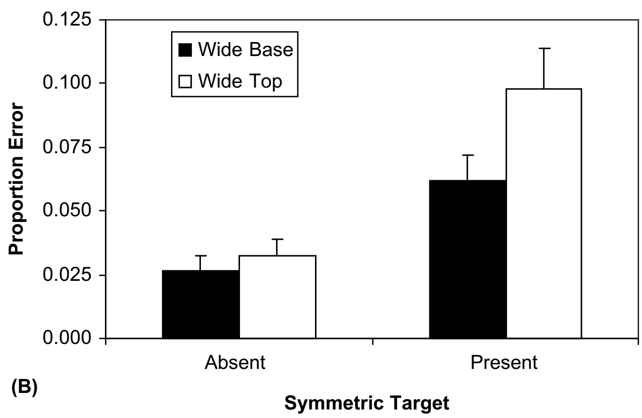


Fig. 6. Results of Experiment 3: (A) reaction times and (B) error rates. Black: wide base stimuli. White: wide top stimuli. Left: symmetric target absent. Right: symmetric target present. The error bars indicate standard errors.

ing trials, whereas the reaction time analysis only used the correct trials.

A three way repeated measures ANOVA (top–bottom polarity × target presence × color) on the reaction time data yielded significant main effects for target presence, $F(1,15) = 55.9$, $p < 0.001$ and top–bottom polarity, $F(1,15) = 15.8$, $p < 0.002$. Present responses were faster than absent, and responses to targets with a wide base were faster than responses to targets with a wide top. There were no other significant main effects nor were there any significant interactions.

A similar ANOVA on the error-data resulted in significant main effects for target presence, $F(1,15) = 17.9$, $p < 0.002$, and top–bottom polarity, $F(1,15) = 17.8$, $p < 0.002$. Moreover, there was a significant interaction between target presence and top–bottom polarity, $F(1,15) = 8.6$, $p < 0.011$. There were more errors on present trials than on absent trials, and fewer for targets with a wide base than for targets with a wide top. This advantage for wide-base targets was most pronounced on target present trials. For all the other main effects and interactions, the p-values were larger than 0.2.

4.4. Discussion

We consider the figural search task as a form of visual search in which participants have to select a symmetrical target from asymmetric distractors. Olivers and Van der Helm (1998) have shown that visual search for a symmetrical target is inefficient, and the long reaction times and high error rates for the present figural search task are consistent with this. More interesting is that figural search was affected by the top–bottom polarity of the target shape, even though the color of the target was pre-specified so that participants should have been set to organize figure–ground relations on the basis of color. For the reaction time measure, the effect was quite substantial and equally large on present and absent trials (an overall effect of around 100 ms). In addition to this, there was a high error rate, with targets with a wide top being particularly hard to detect (a miss rate of nearly 10%). However, even though there are more errors on present trials than on absent trials, there are always more errors in the wide top condition than in the wide base condition. So the polarity effect we observe is not caused by speed-accuracy trade-off.

The long reaction times and high miss rate for wide-top targets may come about because top–bottom polarity is a powerful factor influencing figure–ground organization. To detect a target with a wide top, participants must create and maintain a representation in which the wide top stimuli are coded as 'figure', and the wide base stimuli as 'ground'. The data suggest that it is difficult to do this.

Symmetry has repeatedly been reported as a determiner of figure and ground (e.g. Driver & Baylis, 1996; Palmer, 1999). However, the 100 ms difference between the wide base and the wide top conditions cannot be attributed to the presence or absence of a symmetric target. Both the wide base and the wide top conditions contained the same number of symmetrical targets. If symmetry biased the assignment of figure and ground, we would have expected to find no difference between the wide base and the wide top conditions.

However, other accounts are still possible. For example, it may simply be that visual search through items with a wide top is more difficult than search through items with a wide base, and this is unrelated to figure–ground segmentation. Several investigators have demonstrated that visual search is influenced by the perceived orientations of stimuli, with asymmetries favoring oblique over vertical stimuli (Treisman & Souther, 1985) and stimuli in unusual over 'standard' orientations (Wolfe, 2001). Given the similarities between visual search and our figural search tasks, it may be that, in Experiment 3, we witness an asymmetry, favoring items with a wide base over items with a wide top (Note that this would actually constitute a case of a standard orientation being favored). The results of Experiments 1 and

2, where we found an effect of top–bottom polarity on figure–ground assignment with tasks that are unrelated to visual search, suggest it is unlikely that a search assymmetry is the only explanation, but it might be a contributing factor. To test this, in Experiment 4, we included a new manipulation. In one condition we used stimuli with ambiguous figure–ground relations (as in Experiment 3), but this time we allowed the targets to be either black or white on a trial. Thus color was no longer a reliable cue to figure–ground organization. If part of the benefit to wide base stimuli in Experiment 3 was because they bias figure–ground assignment, then even stronger effects of top–bottom polarity could occur here, since the moderating effect of another factor (the color cue) was eliminated.

In the second condition, participants were presented with displays in which individual search elements did not have ambiguous figure–ground relations (for the most part being completely surrounded by the overall gray background). This condition was included because pilot work indicated that the figural search task without color instruction was quite difficult. We therefore felt it was necessary to include an 'easy' condition, in order to keep the participants motivated. Moreover, if figural search is indeed comparable to visual search, this unambiguous condition should yield reaction times similar to those in Experiment 3.

So, both the ambiguous and the unambiguous configuration conditions of Experiment 4 are to be compared with the results of Experiment 3, rather than with each other.

5. Experiment 4: figural search for an unknown target color

5.1. Method

5.1.1. Participants

Sixteen participants (13 female, 3 male) were recruited, either in return for course credit or for a small payment. All had corrected or corrected-to-normal vision, and they were unaware of the purpose of the experiment.

5.1.2. Apparatus

The apparatus was the same as used in Experiment 3.

5.1.3. Stimuli

The ambiguous stimuli used in this experiment were the same as those used in Experiment 3. The unambiguous stimuli were closely related to the ambiguous forms (see Fig. 7 for examples of displays with unambiguous figure–ground relationships). The individual shapes were identical to the shapes in the ambiguous displays. The background rectangle was again included, and had the same dimensions as the ambiguous stimuli ($3.7° \times 12.4°$). However, for the unambiguous displays the individual shapes were vertically displaced to enable them to be unambiguously coded as 'figures' (being small closed shapes against a much larger background). The screen was subdivided into five horizontal bands (2.3° wide), and each of the objects was randomly positioned in one of the bands. The maximum vertical overlap between two neighboring objects was 1.4°. The maximum height of an unambiguous display was therefore 14.4°, the minimum height 10°. There was no horizontal overlap, because the objects had horizontal positions similar to those in the ambiguous displays. For each of the wide base displays the configuration (dispersion) of the objects was chosen randomly, and the same configuration was then used for the wide top displays. Again two color versions of the stimuli were used, and both these color versions were also inverted.

5.1.4. Procedure

The participants were tested individually in a session that lasted approximately 40 min. They were first given the instructions for their task, and then they performed a practice block of 16 trials. When the participants felt at ease with the task, they would start the experimental blocks, otherwise they would get another practice block of 16 trials.

A trial consisted of a fixation cross presented in the center of the screen for 1000 ms. After the fixation cross disappeared, the stimulus display was presented until the participant responded or 30,000 ms had passed. After the response, there was an inter-trial interval of 1000 ms, before a new trial would start. The task was to look for a vertically symmetric object. It could be either black or white, and it was each color equally often. If the target was present participants had to push the present key on the keyboard as quickly as possible. If it was absent, they had to push the absent key. Responses were made using the 'Z' and 'M' keys, with the key used for the response counter-balanced over participants. Ambiguous and unambiguous displays were intermixed.

5.1.5. Design

There were four within-subject factors: configuration (ambiguous, unambiguous), top–bottom polarity (wide base, wide top), target presence (symmetric target present, symmetric target absent), and the color of the stimuli (black, white). All the factors were fully crossed. In total, there were 512 trials. There were eight blocks, containing 64 trials each. Between every block there was a self-paced break for the participant. Pilot work indicated high error rates, so we did not retake any of the error trials, to prevent demotivation of the participants.

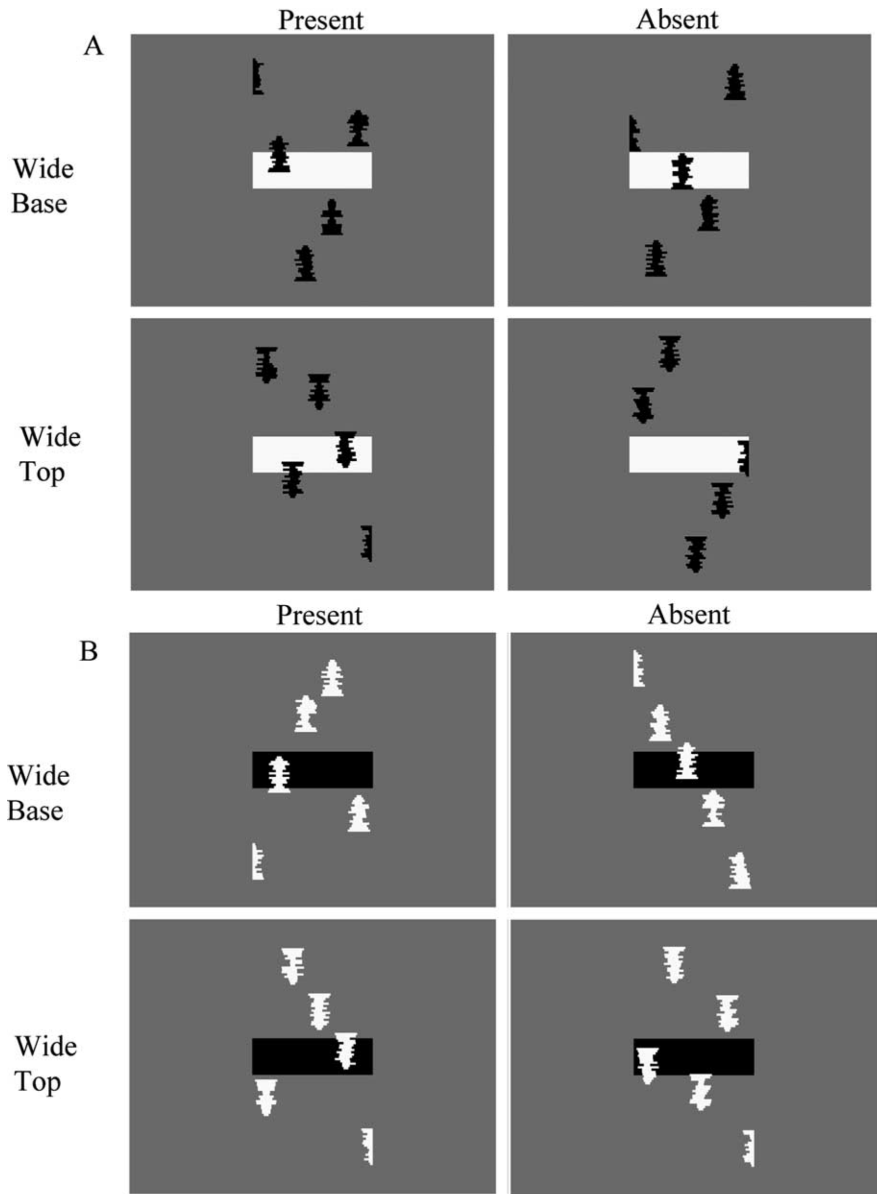


Fig. 7. Examples of displays with unambiguous figure–ground relations used in Experiment 4: (A) unambiguous black targets and (B) unambiguous white targets.

5.2. Results

The results are shown in Fig. 8. Responses greater or less than 2.0 SDs from the cell mean (configuration × top–bottom polarity × target presence × color) for each participant were rejected. This resulted in rejection of 4.3% of the data. The error analysis was performed on all of the remaining trials, whereas the reaction time analysis only used the correct trials.

A four-way repeated measures ANOVA on the reaction time data yielded a host of significant main effects and interactions. All four main effects were significant: configuration $F(1,15) = 31.0$, $p < 0.001$, target presence $F(1,15) = 63.0$, $p < 0.001$, top–bottom polarity $F(1,15) = 11.5$, $p < 0.004$ and color $F(1,15) = 14.5$, $p < 0.002$. Moreover, there were significant interactions between configuration and target presence $F(1,15) = 15.8$, $p < 0.002$, configuration and top–bottom polarity $F(1,15) = 7.7$, $p < 0.015$, configuration and color $F(1,15) = 4.8$, $p < 0.045$, and a three way interaction between configuration, target presence and color $F(1,15) = 8.0$, $p < 0.015$. To analyze the data further, we separated the results for ambiguous and unambiguous configurations.

For the unambiguous configuration, there was only a significant effect of target presence $F(1,15) = 82.4$,

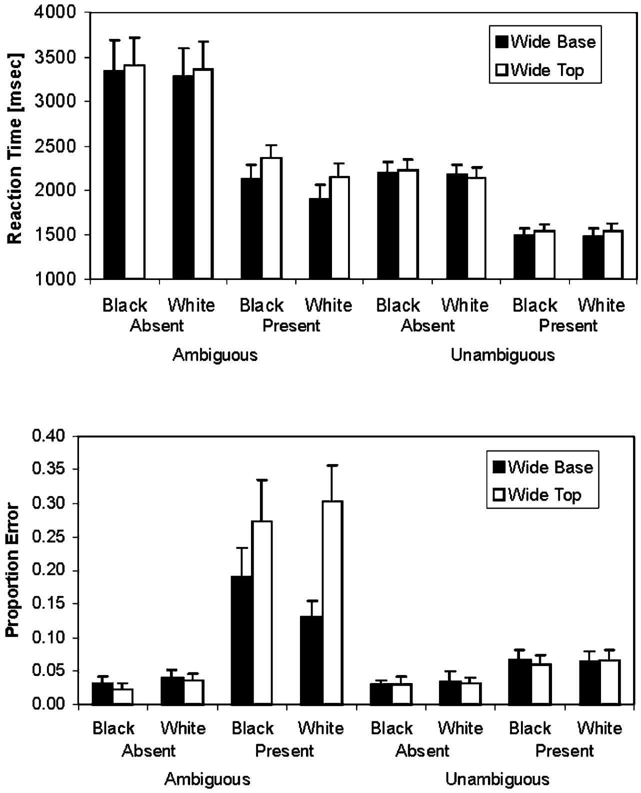


Fig. 8. Results of Experiment 4 as a function of color, target presence and the ambiguity of figure–ground relations. Top panel: reaction times. Bottom panel: error rates. The error bars indicate standard errors.

$p < 0.001$. None of the other main effects or interactions approached significance (p's > 0.15).

For the ambiguous configuration, there were significant main effects of target presence $F(1,15) = 82.4$, $p < 0.001$, top–bottom polarity $F(1,15) = 12.4$, $p < 0.004$ and color $F(1,15) = 10.4$, $p < 0.006$. No interactions were reliable with a Bonferroni corrected α of 0.025. Reaction times were faster on present than absent trials, for white relative to black shapes, and for targets with a wide base relative to targets with a wide top.

A four-way repeated measures ANOVA on the error data resulted in significant main effects of configuration, $F(1,15) = 23.7$, $p < 0.001$, target presence, $F(1,15) = 26.0$, $p < 0.001$, top–bottom polarity, $F(1,15) = 8.8$, $p < 0.01$. Moreover, there were significant interactions between configuration and target presence, $F(1,15) = 16.7$, $p < 0.001$, between configuration and top–bottom polarity, $F(1,15) = 8.9$, $p < 0.01$, and target presence and top–bottom polarity $F(1,15) = 7.7$, $p < 0.015$. There was also a three-way interaction between configuration, target presence and top–bottom polarity, $F(1,15) = 11.2$, $p < 0.005$. Splitting the analysis along the configuration dimension, for unambiguous stimuli there was only a significant effect of target presence, $F(1,15) = 7.5$, $p < 0.02$. For ambiguous stimuli there were significant main effects of target presence, $F(1,15) = 23.2$, $p < 0.001$ and top–bottom polarity, $F(1,15) = 9.8$, $p < 0.005$ and an interaction between the two, $F(1,15) = 9.5$, $p < 0.01$. The error rate was greater on present than absent trials, and for targets with a wide top relative to a wide base. There was no effect of color and no reliable interactions involving this factor after Bonferroni-correction.

5.3. Discussion

There are several interesting aspects about the results. First, we found a substantial effect of top–bottom polarity in the ambiguous displays. However, this the effect of polarity on reaction times was only apparent on present trials ($t(15) = 3.28$, $p < 0.006$) and not on absent trials ($t(15) = 0.90$, $p < 0.38$). This is understandable. In order to establish that there is no target present, the participants will have to search through all the items in the display, with both figure–ground assignments. Consequently, any effect of top–bottom polarity on initial figure–ground assignment would be minimized. In contrast, target present trials should be influenced by the initial figure–ground assignment, which in turn is modulated by the top–bottom polarity of the shapes. Targets would be found faster when they are revealed by the first figure–ground assignment rather than following a second assignment process.

The second result of interest is that, for exactly the same (ambiguous) displays, the polarity effect on present trials was larger in Experiment 4 than Experiment 3 (one-sided $t(30) = 1.9$, $p < 0.035$). Since the ambiguous displays were generated in exactly the same way for both experiments, the enhanced effect probably reflects the fact that participants could use top-down knowledge about the target's color in Experiment 3, but not Experiment 4, although differences in response strategies between the experiments can not be totally excluded. In Experiment 3, foreknowledge of the target's color should have helped to bias figure–ground assignment, counter-acting any bias from the top–bottom polarity of the shapes. When the color bias was reduced (in Experiment 4), a stronger effect of top–bottom polarity emerged.

Thirdly, we note that RTs for the unambiguous displays are in the same ball park as those for the ambiguous displays in Experiment 3 ($t(30) = 1.32$, $p < 0.196$). This is consistent with our suggestion that figural search is comparable to visual search.

The combination of results from Experiments 3 and 4 also discounts two alternative explanations that might be suggested for the observed effects of top–bottom polarity in figural search.

The first of these is that the results reflect an effect of top–bottom polarity on symmetry detection per se (i.e. that it may simply be the case that it is easier to detect a symmetrical target when it has a relatively wide base and a narrow top than vice versa). Indeed, in another paper (Hulleman & Humphreys, 2004) we have shown that there actually is at most a 10 ms advantage for the detection of vertical symmetry in a single wide-base stimulus relative to a wide-top stimulus. A much larger advantage would be necessary to explain the 100 ms difference we found in Experiment 3. Moreover, even if we would assume that the reaction time advantage for symmetry detection in wide-base stimuli could be larger in the ambiguous displays we have used in Experiments 3 and 4, the results of Experiments 3 and 4 cannot be brought into register using differences in symmetry detection alone. An explanation purely based on differences in symmetry detection would predict a smaller effect of top–bottom polarity in Experiment 4. In Experiment 3, the participants know the target color and will therefore only select the items in that color (the fact that the RTs in the unambiguous condition of Experiment 4 are on a par with the RTs in Experiment 3 suggests that this is the case). Hence, in Experiment 3, the reaction time difference between wide base and wide top targets should be maximal, because the reaction times in either condition will solely be based on the 'quick' wide base items and the 'slow' wide top items, respectively. In Experiment 4, the participants do not know the target color beforehand. Hence, they may frequently select the 'wrong' target color. This will reduce the reaction time difference between the wide-base and the wide-top condition, because the reaction times in both conditions will be based on a mix of the 'slow' wide-top and 'quick' wide-base items. However we observed exactly the opposite: the difference between the wide-top and wide-base conditions increased in the target present condition of Experiment 4 compared with Experiment 3.

Second, the effect of top–bottom polarity cannot be attributed to a speed–accuracy trade-off. It is true that there were more errors on target present than on target absent trials, particularly for the displays with ambiguous figure–ground relations in Experiment 4. This pattern, with more errors on target present than on target absent trials, is quite common in visual search tasks. Typically the result is taken to reflect the early termination of search on target present trials, prior to the target being detected (e.g. Chun & Wolfe, 1996). In our experiments this early termination of search is most likely to have occurred when the participants assigned the region that contained the target to be ground. The resulting figural area would contain four asymmetric search items. After finishing the search of these four items, the participants probably were tempted to terminate their search, rather than attempt to reverse the figure–ground assignment and search the four remaining items. This mind set would have been encouraged by the non-ambiguous stimuli, that effectively contained only four search items.

The result does not detract from the effects of top–bottom polarity on performance however. The critical aspect of the data is that there are more errors for wide top items than for wide base items. Here, the error pattern follows the RT pattern exactly. There are less errors in the quick wide base condition, irrespective of whether the general error level is higher, like on present trials, or lower, like on absent trials. We suggest then that participants conduct a search task based on a representation parsed into figure and ground regions, and that this regional assignment is influenced by the top–bottom polarity of the shapes. It could be argued that the RTs in Experiment 4 are too long to reflect the influences of figure–ground assignment. However, visual search for symmetry is very slow (see also Olivers & Van der Helm, 1998). So, even when the appropriate figure–ground assignment takes place, to enable the target to be selected, RTs will remain long and likely affected by the number of figural regions in the display. In addition, there will be large costs on performance if the 'wrong' color is initially interpreted as defining the figural regions (e.g., for wide top targets, where the figural assignment might first be given to the wide base regions).

6. General discussion

We have reported four experiments into the effects of the top–bottom polarity of spatial regions on figure–ground organization. In Experiment 1, wide base regions were reported as figure, in preference to wide top regions, in a substantial majority of participants. In Experiment 2, a VSTM-task suggested that participants prefer a wide base shape as a figure. Experiments 3 and 4 provided additional evidence for the influence of top–bottom polarity on figure–ground assignment.

In Experiment 3 participants were set to detect a symmetric target in a given color, when there were ambiguous figure–ground relations between the parts of the display. Despite participants being set to code the display on the basis of color, we found effects of the top–bottom polarity of the stimuli on performance. It was harder to detect a target with a wide top relative to a target with a wide base. In Experiment 4, we examined the same task with the same ambiguous stimuli. This time however, participants were not given information about the target's color beforehand. Under these conditions the effects of top–bottom polarity on performance were far larger than in Experiment 3, where any biasing effect of polarity on figure–ground assignment could be counter-acted by foreknowledge of the target's color. This interaction between polarity and foreknowledge of the target's color (in Experiment 4 vs Experiment 3), is difficult to explain if polarity only influenced symmetry detection. However, the results from Experiments 3 and 4 fit with the proposal that top–bottom polarity influences figure–ground assignment.

In sum, our results converge in suggesting that top–bottom polarity is one factor which, along with others, contributes to figure–ground coding. Indeed, the combined influence of factors is demonstrated by the contrasting strength of the polarity effects in Experiments 3 and 4. In Experiment 3, the influence of top–bottom polarity was moderated by top-down parsing by color into figure and ground.

Prior studies of figure–ground coding have not indicated that top–bottom polarity is a critical factor, though factors such as object familiarity ('denotivity' in Peterson & Gibson's, 1994 terms) have been shown to play a part and object familiarity is likely reduced by inversion (e.g., see Jolicoeur, 1985). It might be argued that the wide base stimuli we used in our experiments look like the silhouettes of evergreen trees. Since these are familiar shapes, this might have driven figure–ground assignment, rather than top–bottom polarity. However, there are several difference between the wide base regions and evergreen trees. First, the silhouettes of evergreen trees tend to be vertically symmetrical, due to their exposure to gravity. All wide base regions in Experiments 1 and 2, and most wide base regions in Experiments 3 and 4 were asymmetrical. Second, the silhouette of an evergeen tree tends to be a smooth curve, unlike the serrated envelopes of the wide base regions in our experiments. Third, because evergreen trees are trees, they actually have a narrow base: their stem sticks out from underneath the branches. Moreover, it could be argued that the wide top shapes look like the tornade shapes that are familiar from weather programs and disaster movies. Clearly there was no advantage for these forms. Another argument against familiarity as an explanation of our results are the stimuli used by Peterson and Gibson (1994). Their displays contained regions with easily recognisable shapes that had to compete against regions with no reasonable object interpretation at all. Even under those more ideal circumstances Peterson and Gibson (1994) reported for the condition where both the high and the low denotative regions were asymmetric (comparable to our Experiment 2) only a 61% preference for the high denotative regions. It seems inappropriate to call either the wide base or the wide top stimuli in Experiment 2 highly denotative, suggesting also that the influence of familiarity on the outcome of Experiment 2 was minimal.

As we have noted, Vecera et al. (2002) proposed that there is a tendency to code the lower region of a stimulus as figure and the upper as ground, when a display segments into distinct upper and lower regions. From this it might be argued that, here, the bottom part of the shapes was strongly weighted in figure–ground organization, so that there was a bias to code a stimulus as figure if it had a wide/stable bottom part. So, rather than a new figure–ground cue, the top–bottom polarity should be considered as an extension of the lower region cue. However, in our case, whole shapes (top, as well as bottom parts) were coded as 'figure', so there was no simple parsing of the display into bottom and top halves. Indeed, unlike Vecera et al. (2002), the bottom half of the displays contained ground as well as figural elements. Furthermore, the difference in the distribution of the area between wide base and wide top stimuli was relatively minor. In Experiment 2, the centres of mass were, on average, respectively some 6% of the height of the stimuli below and above the midline of the displays. So, most of the time, the centres of mass of the wide base stimuli were in the fifth horizontal strip from the bottom, just under the midline of the display. Describing this situation as lower region probably stretches beyond the point where it is useful to use the concept. This is especially the case the stimuli with 16 horizontal strips (used in the other experiments), where the centres of mass fell even closer to the middle.

Now, when given a choice as to whether a 'wide base' or a 'wide top' stimulus is upright, independent observers routinely choose the 'wide base' stimulus. Thus the effect of top–bottom polarity on figure–ground assignment may well reflect a more general bias in visual coding, favoring objects that appear stable when aligned with the gravitational upright.

It is important to point out that our argument for the effects of top–bottom polarity on figure–ground coding comes from several sources. First, we found the bias when we employed an explicit reporting task. Second, we observed the same bias when we employed a VSTM-task. Third, we also found the effect of top–bottom polarity in a novel task that depends on figure–ground assignment, but is not directly contingent on introspective factors. This convergence of results not only supports the conclusion that top–bottom polarity is a figure–ground cue, it also suggests that figural search has some credence as a method in figure–ground research. We propose that figural search is a welcome addition to the instruments at the disposal of researchers interested in figure–ground assignment.

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References

Baylis, G. C., & Driver, J. (2001). Perception of symmetry and repetition within and across visual shapes: Part-descriptions and object-based attention. *Visual Cognition, 8*, 163–196.

Chun, M. M., & Wolfe, J. M. (1996). Just say no: How are visual searches terminated when there is no target present? *Cognitive Psychology, 30*, 39–78.

Driver, J., & Baylis, G. C. (1996). Edge-assignment and figure–ground segmentation in short-term visual matching. *Cognitive Psychology, 31*, 248–306.

Hulleman, J., & Humphreys, G. W. (2004). Is there an assignment of top and bottom during symmetry perception? *Perception, 33*, 615–620.

Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory and Cognition, 13*, 289–303.

Metzger, W. (1936). *Gesetze des Sehens (Laws of seeing)*. Frankfurt am Main: W. Kramer & Co.

Olivers, C. N. L., & Van der Helm, P. A. (1998). Symmetry and selective attention: A dissociation between effortless perception and serial search. *Perception and Psychophysics, 60*, 1101–1116.

Palmer, S. E. (1999). *Vision Science: Photons to Phenomenology*. Cambridge, MA: MIT Press.

Peterson, M. A., & Gibson, B. S. (1994). Must figure–ground organization precede object recognition—an assumption in peril. *Psychological Science, 5*, 253–259.

Strüber, D., & Stadler, M. (1999). Differences in top-down influences on the reversal rate of different categories of reversible figures. *Perception, 28*, 1185–1196.

Treisman, A., & Souther, J. (1985). Search asymmetry—a diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General, 114*, 285–310.

Vecera, S. P., Vogel, E. K., & Woodman, G. F. (2002). Lower region: a new cue for figure–ground assignment. *Journal of Experimental Psychology: General, 131*, 194–205.

Wolfe, J. M. (2001). Asymmetries in visual search: an introduction. *Perception and Psychophysics, 63*, 381–389.